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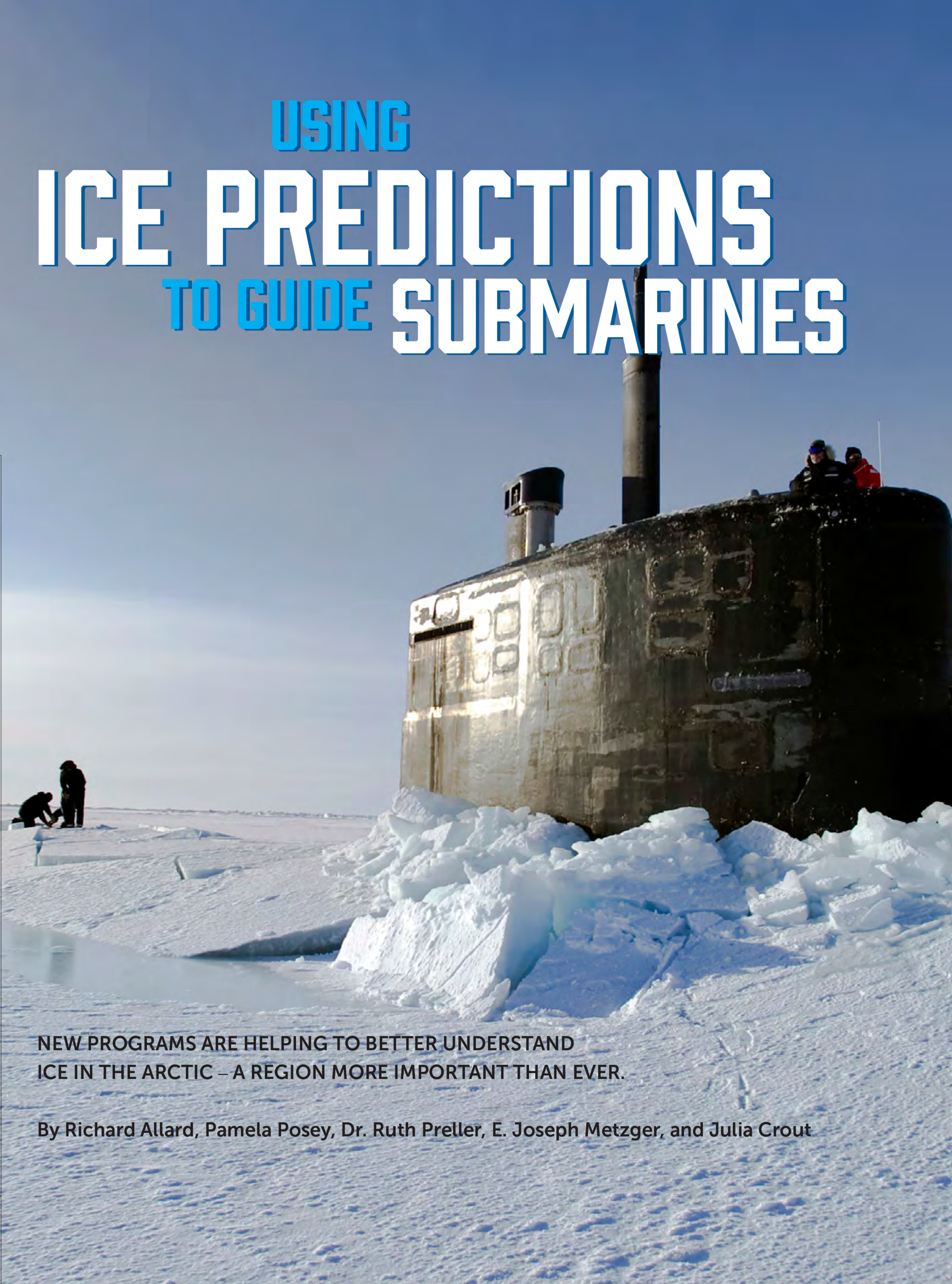


NEW PROGRAMS ARE HELPING TO BETTER UNDERSTAND ICE IN THE ARCTIC – A REGION MORE IMPORTANT THAN EVER.

By Richard Allard, Pamela Posey, Dr. Ruth Preller, E. Joseph Metzger, and Julia Crout

Photo by MC2 Kevin S. O'Brien

Sailors and members of the Applied Physics Laboratory Ice Station clear ice from the hatch of the submarine USS *Connecticut* (SSN 22) during Ice Exercise (ICEX) 2011.

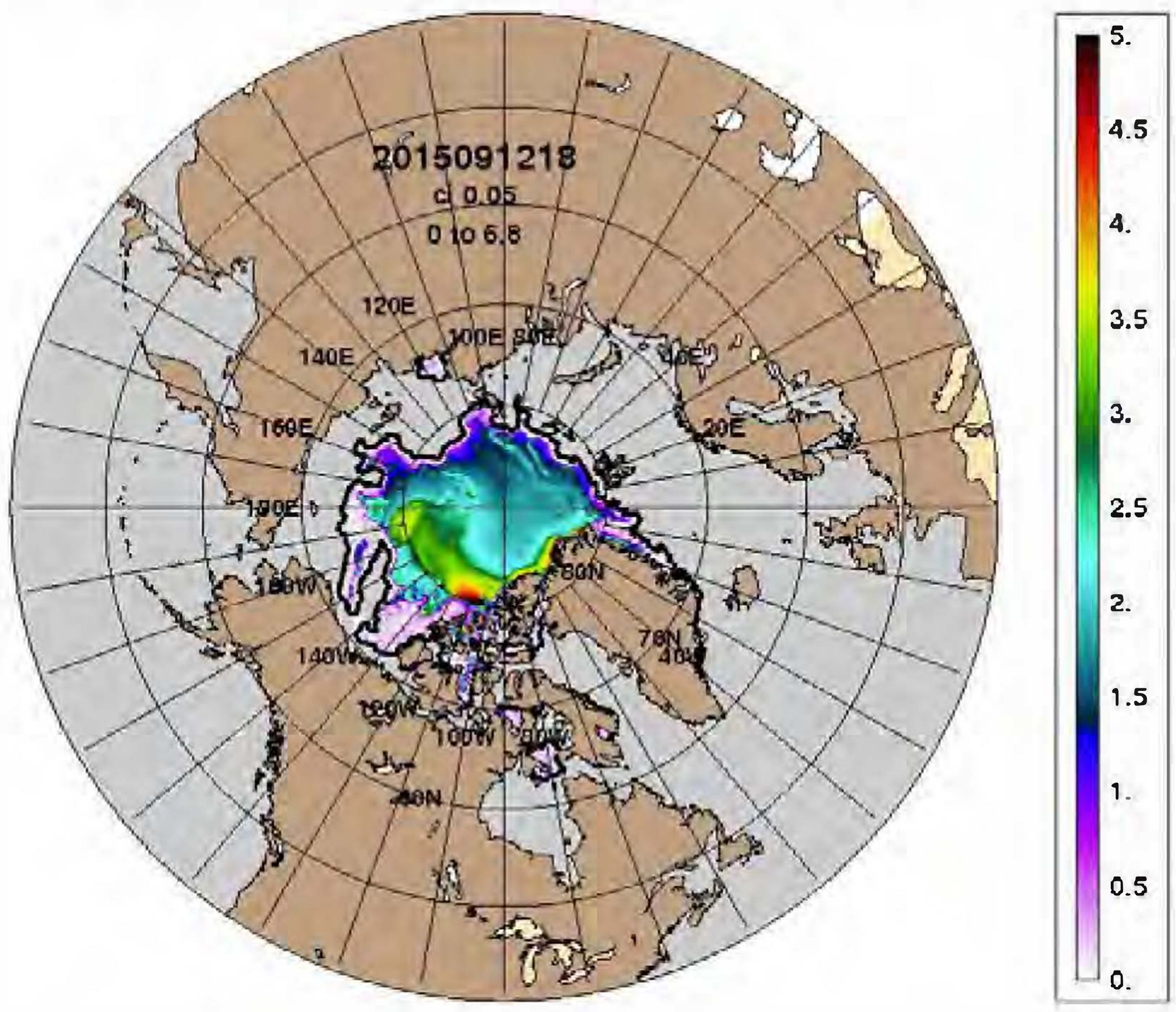
Whether an Arctic mission requires the use of an icebreaker, Navy ships in open water, unmanned aerial or underwater vehicles, or even a submarine, knowledge of environmental conditions are of great importance to mission success and safety. For more than 50 years, submarines have conducted under-ice operations in the Arctic in support of interfleet transit, training, cooperative allied engagements, and other operations. A significant effort that occurs every two to three years is ICEX (Ice Exercise) which provides training opportunities as submarines transit the Arctic Ocean on their way between the Atlantic and Pacific Oceans. ICEX 2014, the most recent exercise, was brought to an unexpectedly early end. The ICEX began on 17 March and was scheduled to continue through 30 March. Large shifts in wind direction, however, created instabilities in the wind-driven ice floes of the Arctic Ocean, and these changes in the prevailing winds led to multiple fractures in the ice near the camp. These cracks prevented the use of several airfields used for transporting personnel and equipment to the ice camp. The rapidly changing conditions of the ice, along with extremely low temperatures and poor visibility, hampered operations.

Submarines transiting under the Arctic ice use a guidance product developed by the National Ice Center called a FLAP (fractures, leads, and polynyas). A lead represents a crack or linear opening in the sea ice caused by divergent ocean current flows or wind effects. Leads are often transient and may quickly refreeze after the surface water encounters very cold air temperatures. A polynya is an area of open water surrounded by sea ice that often remains open because of warm upwelled water or warm coastal air. The FLAP "analysis" product is based on all available satellite imagery and provides a real-time indication of ice opening areas. The FLAP is provided to submarines prior to and during Arctic transits as a formatted text message that identifies navigation features in the ice over large areas. The message contains the latitude/longitude pairs delineating FLAPs, as well as remarks on the orientation and ice types. This is especially useful should the submarine need to surface for communications or in case of emergency and must find a location at which such operations may take place safely.

Scientists from the Oceanography Division of the Naval Research Laboratory developed and transitioned a new Arctic forecast system called the Arctic Cap Nowcast/Forecast System (ACNFS) in September 2013. The ACNFS consists of a coupled ice-ocean model that assimilates available real-time ocean and ice observations. The Global Ocean Forecast System (GOFS) 3.1, currently awaiting

final operational approval, will replace ACN FS in the near future. Using similar components (ice, ocean, and data assimilation), GOFS 3.1 is a global coupled ice-ocean modeling system that gives the Navy the capability of forecasting ice conditions in both the northern and southern hemispheres. The ice component used for both systems is the Los Alamos Community Ice Code, a widely accepted model used in the ice community. ACNFS and GOFS 3.1 assimilate near-real-time observations of ocean temperature profile data (both in open water and under the ice), satellite-derived sea surface temperature and ice concentration, and satellite altimetry data. ACNFS and GOFS 3.1 are forced with atmospheric winds and heat fluxes from the Navy Global Environmental Model. Both systems have high horizontal resolution (3.5 kilometers at the North Pole) and generate seven-day forecasts of ice thickness, ice concentration, ice drift, ocean surface and subsurface temperature, salinity, ocean current, and 40 additional two-dimensional products. Both systems are run daily at the Naval Oceanographic Office with products automatically pushed to the National Ice Center for guidance in developing daily/weekly ice charts.

Prior to the operational acceptance of these forecast systems, the National Ice Center actively takes part in performing an evaluation of these modeling systems, with particular emphasis on evaluating the predictive skill of the ice products of the models. One of those products is the lead opening rate, which provides information on areas where new leads may form or grow based on divergence of the ice pack, typically produced by wind force acting on the ice. Although not part of the initial validation process, the National Ice Center asked the Naval Research Laboratory's Oceanography Division to validate ACNFS and GOFS 3.1 by evaluating the systems' relative skill at predicting the areas where FLAPs would develop.

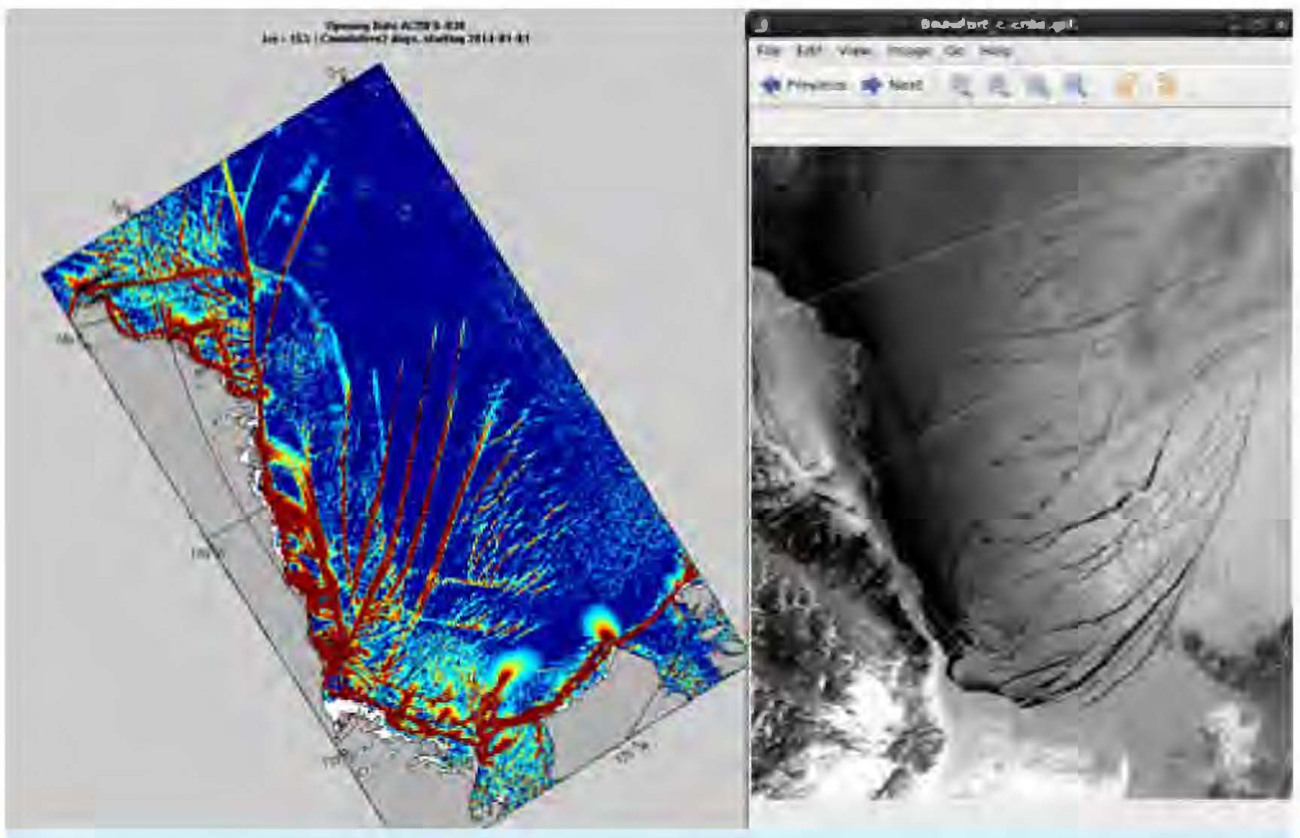


An example product from the Arctic Cap Nowcast/Forecast System (ACNFS). Ice thickness is in meters for 11 September 2015. Thickness ranges from zero to five meters as shown in color bar. Gray areas represent open water. The thick black line is an independent ice edge analysis from the National Ice Center.

The ACNFS and GOFS 3.1 capabilities were then extended to capture and predict the opening of sea ice areas (fractures/leads) and polynyas by calculating areas of

Confronting an Icy Domain

Military operations carried out in the harsh Arctic environment can be very challenging. Winter air temperatures can plummet to -40 degrees Fahrenheit or colder, high winds and breaking waves occur, and a continuously changing ice cover can make previously open water regions impassable. In recent years the Arctic has experienced numerous changes. These include an overall thinner ice cover, an increase in open water in the summer, and larger waves. The National Snow and Ice Data Center, which monitors Arctic sea ice from satellite observations, has observed a substantial reduction in summer sea ice extent when compared to the 30-year average (1981-2010) and have recently stated that the summer sea ice extent in 2015 was the fourth lowest recorded in the satellite record (behind 2012, 2007 and 2011). In addition, the nine lowest summer ice extents in the satellite era have all occurred in the last nine years. Satellite data and drifting buoy information can also be used to determine the "age of the ice cover. The age of the sea ice serves as an indicator of its physical properties including surface roughness, melt pond coverage, and thickness. Older ice tends to be thicker than younger ice. These observations indicate that although there are year to year fluctuations in the amount of old versus new ice, the amount of old ice has been greatly reduced since the 1980's when the oldest ice made up a larger fraction of the pack. These recent changes in the Arctic environment make the prediction of sea ice conditions based on climatology, mean conditions, or even the previous year's conditions impractical.



ACNFS opening rate in percentage/day (left) and MODIS imagery (right) valid for 1 January 2014 for the Beaufort Sea area. Black areas on imagery indicate leads and open water.

ice convergence and divergence, ice opening rates, ice ridging, and ice shear. The ACNFS and GOFS 3.1 opening rate is an instantaneous value representing how fast an opening event is occurring. It does not, however, reflect ice opening from previous days. An innovative technique—using weighted model-derived opening rates from the three prior days to the analysis time as well as calculated convergence over that time—generated the validated ACNFS and GOFS 3.1 FLAP analysis product. A key advantage is that the ACNFS and GOFS 3.1-derived FLAP analysis can provide valuable information in cloud covered areas or other areas where satellite imagery may not be available.

Knowledge of where openings are currently present is most important for daily ship and submarine navigation; knowledge of the future timing and location of significant fracturing is most important for operations planning. As such, the National Ice Center also expressed an interest in the ability to provide five-to-seven day FLAP forecasts for mission planning. To meet this need, the Naval Research Laboratory used their ACNFS and GOFS 3.1 forecast systems to provide a new capability—a seven-day forecast product of opening rates that represent areas of FLAPs in the Arctic. This capability has been developed, demonstrated, validated, and transitioned to the Naval Oceanographic Office and is provided daily to the National Ice Center. These forecasts show substantial improvement over persistence and can be used as guidance to support planning and decision making for Arctic missions.

Both ACNFS and GOFS 3.1 opening rate products were validated for an 11-month period of FLAP messages from January through November 2012 provided by the National Ice Center. The FLAP messages (around 80 classified text files) provided reference data to validate the AC NFS and GOFS 3.1 analysis and forecasted products. For each message, the number of fractures and polynyas along with the orientation were noted. Comparison metrics were completed for each message fracture noting the model agreement category as strong match, partially covered, location off, subset of field, or no match. A combined "hit/near hit" was achieved at a rate of 88 percent for all the model test cases evaluated during the 11-month period. Locating the "near hit" areas is just as valuable as a "hit" to a submarine, which will then know the general area to use their upward-looking sonar to locate a safe place to surface. During this evaluation, the modeled products were compared against satellite imagery, such as the Moderate-resolution Imaging Spectroradiometer and NASA's Visible Infrared Imagery Radiometer Suite.

In August 2015, the National Ice Center determined that the AC NFS and GOFS 3.1 products were useful to ice analysts as a resource to develop special support and FLAP products for their customers.

The ice-ocean coupled models that form the basis of the forecast systems described in this article will soon become the oceanographic component of the Navy's Earth System Prediction Capability (ESPC). ESPC will be a global model that includes coupled ice-ocean-wave-atmosphere models that assimilate all available observations. The coupled system should provide better and longer forecasts for the globe resulting in even better forecasts of Arctic environmental conditions that impact Navy missions. This program funded by the Oceanographer of the Navy and managed by the Office of Naval Research is part of the larger national ESPC effort.

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